

Load Impact Analysis Towards Power Loss in Distribution Substation in Wlingi District

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Abstract

This research aimed to find: (1) the distribution substations configuration in Kesamben Feeder, Wlingi District, (2) how much was the loading in those distribution substations, (3) how much load imbalance in the distribution substation's load, and (4) how much was the power loss towards the imbalance load. This research used descriptive analysis by analyzing the loading imbalance towards the power loss of distribution substation in one feeder. The results showed that the higher percentage of loading imbalance meant higher power loss. However, although an imbalance percentage was more significant than a smaller percentage, the power loss that occurred might be more substantial due to the probable higher loading percentage so that the power loss in the substation was also influenced by the loading value, apart from the load imbalance.

Keywords

Loading, Load imbalance, Power loss, Substation distribution

1. Introduction

To date, electricity is the main need, be it for daily life and industries. This occurrence is caused by electrical energy that is easy to be transported and converted into other forms of energy. Stable and continuous electricity supply is an absolute condition that should be met in fulfilling the electricity demand [1]–[3]. The distribution system is a system in electrical energy with an essential role because it has a direct correlation with electricity consumption, particularly medium and low voltage electrical energy users. Often, there was an imbalanced load on the phases in a three-phase distribution system or an overload due to the use of electrical appliances from consumers of electrical energy. Load imbalance is a common problem faced by the three-phase system because of the domination of one-phase consumers than three-phase consumers. Although the domination of three-phase consumers does not automatically balance the phase, if there is an unbalanced load on a three-phase system, the neutral wire will flow, and the difference in the load angle is not equal to 120 °, the unbalanced transformer load will appear neutral current [4]–[9].

The higher imbalances in a transformer meant that the transformer experienced one-phase overload due to the higher current flowing in one phase of the transformer. The high load imbalance affecting the neutral current, in which a large neutral current causes more losses and low energy quality influence the distribution system. According to the measurement of distribution substations, the peak load time performed in Wlingi District stated that 12 substations experienced larger neutral current in each semester out of 125 substations. These occurrences were because of load imbalance in the substations. The neutral flow of current in these substations is called losses [10]–[13]. It means that larger neutral current causes losses in the substation. Therefore, there needed research in those 12 substations by considering the configuration, load, load imbalance, and power loss towards the load imbalance in the substations.

This research used a method by understanding the configuration of the substations in Kesamben Feeder, then analyzed and calculated the load, distributed substation imbalance, and power loss. The calculation and analysis were hopefully could inform the Wlingi District of the effects of load imbalance on the losses of substations.

2. Main Theory or Related Current Research

It Distribution substation is a transformer substation building that supplies all electricity for the consumers using medium or low voltage. Distribution substation is a group/combination from connectors from medium and low voltage. The connector for medium voltage in the distribution substation is different following the construction. A transformer is an electrical device that could transport and convert electrical energy from one or more circuit to other circuits through magnetic tow and based on the electromagnet induction principle [14]–[17]. Distribution transformer functions as a converter from medium voltage electrical energy into low voltage before channeled to the consumers. The commonly used distribution transformer is the step-up down 20/0.4 kV type with the JTFR system phase of 380 Volt. Due to voltage drop, the voltage on TR rack was written above the value of 38 Volt so that the voltage on the end of the load becomes 380 Volt.

A. Distribution Substation Loading

The electrical load is anything that is borne by the power plant or anything that requires electrical energy/power [18]. The electrical load in the alternate current is classified into three types: (1) resistive load, load consisting of ohm resistivity components only (resistance) such as heating element and incandescent lamps. This type of load only consumes active load and have a power factor of one voltage and phase current. (2) Inductive load, load consisting of a coil of wire wrapped around a core such as a coil, transformer, and solenoid. This load causes a phase shift in the current and causes lagging. This occurrence is due to the stored energy in the form of a magnetical field and shifts the current phase lagged on the voltage. This load absorbs active and reactive power. (3) The capacitive load has the capacity or ability to store energy that comes from electric charging (electrical discharge) in a circuit. This component causes leading current towards the voltage.

B. Load Imbalance

Load imbalance is a common problem in the three-phase system because of the domination of one-phase customers compared to three-phase consumers. However, the domination of three-phase consumers does not guarantee balance. If there is an unbalanced load on a three-phase system, the neutral wire will flow, and the difference in the load angle is not equal to 120° , the unbalanced transformer load will appear neutral current.

a. Load imbalance conditions mean a condition where:

- 1) The three current/voltage vectors are equal
- 2) All three vectors form 120° angles with each other

Whereas in Figure 1, the imbalance condition is a condition where one or two imbalance conditions unfulfilled. The possibilities of imbalance are three:

- 1) all three vectors are equal but do not form 120° angle
- 2) all three vectors are not the same in value but form 120° angle
- 3) all three vectors are not the same in value and do not form 120° angle

The details are illustrated with a flow diagram below:

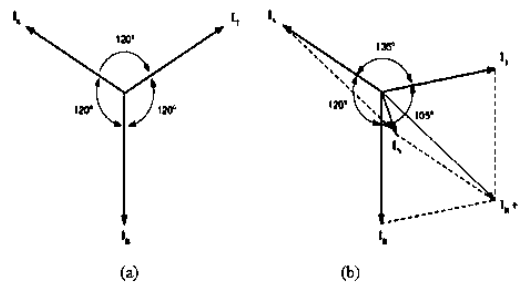


Figure 1. Flow Chart Vector

Figure 1(a) shows the balance current diagram vector as seen from the total current vectors (I_R , I_S , I_T) equal to zero so the neutral current (I_N) appears, amounted to how significant is the imbalance factor.

C. Power Loss on Load Imbalance

Neutral current in the electricity distribution system is the current that flows in the neutral wire in a three-phase 4-wire low voltage distribution system. The neutral current appears if: (a) imbalance load, (b) harmonization current due to non-linear load. The current flowing on a neutral wire which is an alternating current for a three-phase 4-wire distribution system is the sum of the vectors of the three-phase currents in a symmetrical component [19], [20].

3. Method

A. Research Design

This research used a descriptive analysis method by analyzing the load imbalance description towards power loss in distribution substation in one feeder. The procedure in this research was analyzing the load in a distribution substation, imbalance in the distribution substation, power loss towards load imbalance in the 20 kV three-phase distribution substation.

a. Data Collecting Step

To obtain suitable data, this research conducted three collecting techniques: (1) observation, is a data collection instrument by observing and systematically recording the researched signs. (2) quoted, an interview is a discussion or meeting with someone in a conversation; interview method in this context means a process in obtaining a fact or data by direct communication (verbal discussion) with research respondents, either by conversation or using technology (long-distance). (3) documentation technique is finding data on the things or

variables in the form of a document, note, book transcription, newspaper, magazine, inscription, meeting notes, agenda, and others.

b. Data Analysis Step

After obtaining suitable data, the next step is analyzing the data using the predetermined method. Data analysis aims to analyze the data to facilitate the conclusion or answering the research questions. Data analysis was performed according to the procedure and theories correlated with load, imbalance, and power loss towards imbalance in the distribution substation.

B. Research Location and Duration

The research location of this study was in Kesamben Feeder, Wlingi District with the exact address of Jl. Panglima Sudirman No. 02, Ngambak, Beru, Wlingi, Blitar. The duration of the research was from January to May 2018. The duration was used to collect historical data on measurement of distribution substation for four semesters, field observation, interviewing the informants, documentation of supporting data, and load balancing.

C. Data Calculation

Data calculation in this study were separated into three parts: load in a distribution substation, imbalance in a distribution substation, and power loss on the imbalance. The process was explained below.

a. Load in Distribution Substation

1) Full load current

$$I_{FL} = \frac{S}{\sqrt{3} \times V} \tag{1}$$

Where,

I_{FL} = full load current (A)

S = transformer power (kVA)

V = secondary side voltage of the transformer (V)

2) Average current

$$I_{average} = \frac{I_1 + I_2 + I_3}{3} \tag{2}$$

Where,

$I_{average}$ = average current (A)

I_1 = current at R-phase (A)

I_2 = current at S-phase (A)

I_3 = current at T-phase (A)

3) Loading percentage

$$\text{Loading percentage (\%)} = \frac{I_{average}}{I_{FL}} \times 100\% \tag{3}$$

Where,

$I_{average}$ = average current (A)

I_{FL} = full load current (A)

b. Imbalance in Distribution Substation

1) Coefficient of a, b, and c

$$a = \frac{I_1}{I_{average}} \tag{4}$$

$$b = \frac{I_2}{I_{average}} \tag{5}$$

$$c = \frac{I_3}{I_{average}} \tag{6}$$

Where,

$I_{average}$ = average current (A)

I_1 = current at R-phase (A)

I_2 = current at S-phase (A)

I_3 = current at T-phase (A)

2) Percentage of average load imbalance

$$\text{Average load imbalance (\%)} = \frac{\{|a-1|+|b-1|+|c-1|\}}{3} \times 100\%$$

c. Power Loss on Load Imbalance

1) Power loss on neutral conductor

$$P_N = I_N^2 \cdot R_N \tag{7}$$

Where,

P_N = power loss on the neutral transformer (Watt)

I_N = current flowing at neutral transformer (A)

R_N = neutral transformer conductor resistance (Ω)

2) Percentage of power loss in the neutral conductor

$$P = S \cdot \cos \varphi \quad (8)$$

Where,

S = apparent power max (VA)

$\cos \varphi$ = power factor

$$\%P_N = \frac{P_N}{P} \times 100\% \quad (9)$$

Where,

P_N = power loss on the neutral transformer (Watt)

P = active power (Watt)

4. Result

A. Distribution Substation Configuration of Kesamben Feeder Wlingi District

Kesamben Feeder got the power supply from Wlingi Main Substation and has a network for 114.720 ms, consisted of 125 distribution substations with the radial distribution network system. From 12 observed distribution substations, all have a one-line diagram and similar components. The difference was in the capacity, one substation has the capacity of 160kVA, six substations have 100kVA capacity, two substations have 50kVA capacity, and three substations have the capacity of 25 kVA.

B. Loading in Distribution Substation

a. Full load current

Below is the calculation of full load current in EH 170 distribution substation in Semester II, 2016 in Kesamben Feeder:

Knowing:

$$S = 160 \text{ kVA}$$

$$V = 400 \text{ V}$$

Solution:

$$I_{FL} = \frac{S}{\sqrt{3} \times V}$$

$$I_{FL} = \frac{160000}{\sqrt{3} \times 400}$$

$$I_{FL} = 230,95 \text{ A}$$

b. Average current

Below is the calculation of average current in EH 170 distribution substation in Semester II 2016 in Kesamben Feeder:

Knowing:

$$I_R = 106 \text{ A}$$

$$I_S = 53 \text{ A}$$

$$I_T = 86 \text{ A}$$

Solution

$$I_{\text{average}} = \frac{I_R + I_S + I_T}{3}$$

$$I_{\text{average}} = \frac{106 + 53 + 86}{3}$$

$$I_{\text{average}} = 81,67 \text{ A}$$

c. Loading percentage

Below is the loading percentage calculation of EH 170 distribution substation in Semester II 2016 in Kesamben Feeder:

Knowing:

$$I_{FL} = 230,95 \text{ A}$$

$$I_{\text{average}} = 81,67 \text{ A}$$

Solution:

$$\text{Loading (\%)} = \frac{I_{\text{rata-rata}}}{I_{FL}} \times 100\%$$

$$\text{Loading (\%)} = \frac{81,67}{230,95} \times 100\%$$

$$\text{Loading percentage (\%)} = 35,36 \%$$

C. Load Imbalance in Distribution Substation

a. Coefficient of a, b, and c

Below is the coefficient calculation of a, b, and c of EH170 distribution substation in Semester II 2016:

Knowing:

$$\begin{aligned} I_R &= 106 \text{ A} \\ I_S &= 53 \text{ A} \\ I_T &= 86 \text{ A} \\ I_{\text{average}} &= 81,67 \text{ A} \end{aligned}$$

Solution

$$\begin{aligned} a &= \frac{I_R}{I_{\text{average}}} = \frac{106}{81,67} = 1,30 \\ b &= \frac{I_S}{I_{\text{average}}} = \frac{53}{81,67} = 0,65 \\ c &= \frac{I_T}{I_{\text{average}}} = \frac{86}{81,67} = 1,05 \end{aligned}$$

b. Percentage of Average Load Imbalance

Therefore, the average load imbalance (%) in EH170 distribution substation in Semester II, 2016:

Knowing:

$$\begin{aligned} a &= 1,30 \\ b &= 0,65 \\ c &= 1,05 \end{aligned}$$

Solution

$$\begin{aligned} \text{Average load imbalance (\%)} &= \frac{\{|a-1|+|b-1|+|c-1|\}}{3} \times 100\% \\ \text{Average load imbalance (\%)} &= \frac{\{|1,3-1|+|1-0,65|+|1,05-1|\}}{3} \times 100\% \\ \text{Average load imbalance (\%)} &= 23,40 \text{ \%} \end{aligned}$$

D. Power Loss on Load Imbalance

a. Power loss on the neutral conductor

Below is the power loss calculation on the neutral conductor of EH 170 distribution substation in Semester II 2016 in Kesamben Feeder:

Knowing:

$$\begin{aligned} I_N &= 72 \text{ A} \\ R_N &= 0,4608 \ \Omega \end{aligned}$$

Solution:

$$\begin{aligned} P_N &= I_N^2 \times R_N \\ P_N &= 72^2 \times 0,4608 \\ P_N &= 4071,63 \text{ Watt} = 4,071 \text{ kW} \end{aligned}$$

b. Power loss percentage on the neutral conductor

Below is the percentage calculation of power loss on the neutral conductor of EH 170 distribution substation in Semester II 2016 in Kesamben Feeder:

Finding the active power value before calculation:

Knowing:

$$\begin{aligned} S &= 160 \text{ kVA} \\ \cos \varphi &= 0,87 \end{aligned}$$

Solution:

$$\begin{aligned} P &= S \times \cos \varphi \\ P &= 160000 \times 0,87 \\ P &= 139,20 \text{ Kw} \end{aligned}$$

After, the percentage can be calculated as below:

Knowing:

$$\begin{aligned} P_N &= 4071,63 \text{ W} \\ P &= 139,20 \text{ kW} \end{aligned}$$

Solution:

$$\begin{aligned} \%P_N &= \frac{P_N}{P} \times 100\% \\ \%P_N &= \frac{4,071}{139,2} \times 100\% \\ \%P_N &= 2,93 \text{ \%} \end{aligned}$$

The EH170 distribution substation has the highest power loss because it also has the highest loading. The power loss of all 12 distribution substations in Semester II 2016 was 13721.07 Watt, in Semester I 2017 was 12406.95 Watt, in Semester II 2017 was 9822.61 Watt, in Semester I 2018 was 12676.71 Watt, whereas the sum of all semesters losses was 48627.34 Watt. The largest power loss occurred in Semester I 2016. The EH331 distribution substations have the highest load imbalance percentage compared to an EH180 distribution substation. This was caused by the higher load percentage in EH180 than in EH331. Thus, besides the load imbalance, the loading in distribution substation also influenced the power loss value in a distribution substation.

5. Conclusion

Kesamben Feeder received power supply from Wlingi Main Substation and had a network for 114.720 ms, consisted of 125 substations with the radial distribution network system. From 12 observed substations, all had a one-line diagram and similar components. The difference from all substations was in their capacity. One substation had a capacity of 160kVA, six substations had 100kVA capacity, two substations had the capacity of 50kVA, and three substations had the capacity of 25kVA. The analysis showed that six substations experienced underload, two substations that overloaded, and four substations in normal condition. The load imbalance occurred in all 12 substations: EH170, EH180, EH331, EH183, EH336, EH263, EH332, EH325, EH173, EH312, EH288, and EH198 above the imbalance standard of 5% in each semester. The higher load imbalance percentage meant higher power loss. However, even though the percentage value of load imbalance is higher than the percentage of load imbalance is smaller, the power loss that occurs can be greater due to the higher load percentage. Thus, the power loss was also affected by the load value. The load balance for EH170 and Eh180 that was conducted to Wlingi District was analyzed, and it occurred that there was a percentage reduction. Previously the percentages were 30.62% and 30.82%, after balancing became 0.69% and 1.09%. Moreover, if previously were 2803.51 Watt and 2388.79 Watt, after balancing were 665.4 Watt and 387 Watt.

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